EPA Regional Priority AFO Science Question Synthesis Document

Introduction and Executive Summary

Workshop Review Draft:
Supporting Documentation for the EPA Regional Science Workshop on Animal Feeding Operations (AFOs) - Science and Technical Support Needs
December 6-9, 2004, College Park, Maryland

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SECTION 1: INTRODUCTION

1.1 Purpose and Scope

This document is intended to assist EPA Regions in identifying, understanding, assimilating, and utilizing the extensive body of research and scientific/technical tools related to animal feeding operations (AFOs). Only AFO research and tools relevant to regional priority science questions, developed as the initial step in this document's preparation, are addressed. This document will be used as supporting documentation for EPA's Regional Science Workshop on AFO Science and Technical Support Needs, to be held December 6-9, 2004, in College Park, Maryland.

1.2 Statement of the Problem

As defined by EPA's Office of Water (40 CFR 122.23), an AFO is a facility where:

(1) Livestock or poultry are confined and fed for a total of 45 days or more in any 12-month period, and

(2) Vegetative cover of any significance (crops, vegetative forage growth, or post-harvest residues) is lacking.

To be considered an AFO, it is not necessary that the same animals are confined for 45 days, the 45 days do not have to be consecutive, and the 12-month period does not have to correspond to a calendar year. The stipulation of the absence of vegetative cover of any significance intentionally excludes operations where animals are maintained on pasture or rangeland. Sources of emissions from an AFO include the animal confinement facility, manure management systems, and any land to which manure is applied.

Concentrated animal feeding operations (CAFOs) are a subset of the population of AFOs that must obtain a federal water pollution permit (i.e., National Pollutant Discharge Elimination System permit). A CAFO is an AFO that either exceeds a size threshold (number of animals confined), exhibits certain water discharge characteristics, or is designated by a local official as contributing significantly to the pollution of surface waters. While the terms CAFO and AFO often are used interchangeably, AFO is the appropriate term for referring to this industry in general.

Animal feeding operations contribute to pollution in air, water, and soil causing ecological damages and risks to human health. The beef, dairy, pork, and poultry industries when combined generate six to ten times as much waste as is generated by humans. The major stressors associated with the generation and disposal of these wastes include nutrients (nitrogen and phosphorous), sediments from runoff, veterinary pharmaceuticals (e.g., endocrine disrupting chemicals, arsenic, ivermectin, and antibiotics), pathogenic organisms, and atmospheric emissions of gases and particulates.

Nutrients can create conditions favorable for eutrophication of receiving waters leading to degradation of water quality, including depletion of dissolved oxygen and harmful algae blooms. These conditions have resulted in fish kills and economic losses in the seafood and tourism industries. Excess nitrate in drinking water can cause human health effects, including methemoglobinemia ("blue baby syndrome"), adverse pregnancy outcomes, and gastric cancer. An additional public health concern related to animal manure is the potential for contact directly and through the human food chain with pathogenic organisms, which can cause zoonotic diseases (animal diseases that can cause infection in humans). Of particular concern are zoonotic diseases caused by bacteria that may have developed antibiotic resistance due to the use of antibiotics therapeutically, prophylatically, and as growth stimulants in animal agriculture. Emissions from AFOs can contribute to troposheric ozone, fine particulate matter, nitrogen deposition, odor problems, and airborne pathogenic organisms.

Much research remains to be done on AFO emissions. A review of current literature shows that suitable data to derive emission factors or to support regulatory decisions are lacking. For example, much of the research has focused on issues of limited scope (e.g., local odor problems, animal health, worker safety). As a result, many studies have not collected information to relate measured emissions to a unit of animal production capacity. Another limitation is the absence of long-term studies that can capture the effect of seasonal variability on the microbial processes responsible for emissions. Studies also are needed to characterize emission differences due to animal age, feeding regiment, and animal management practices, which can vary substantially. Research on emission control measures often has focused on a single substance or single emission point (e.g., a barn or open lagoon) and has not considered the effect of controls on overall emissions from the entire operation. Substantial data gaps exist, therefore, in our ability to defensibly characterize emissions at individual sources, assess the impact of these emissions on the environment, assess regional differences in impacts, determine the best management practices to reduce emissions, and assess the performance of emission control technology.

1.3 Background

There is a broad variety of environmental impacts associated with AFOs, which EPA Regional offices must address on a regular basis, including: excess nutrients, sediments from runoff, aerosols, veterinary pharmaceuticals, metals, hormones, and pathogens. To address a more narrowly defined set of Regional AFO science needs, the Office of Research and Development's Office of Science Policy (OSP), in collaboration with the regions, Office of Research and Development laboratories and centers, and the Offices of Air and Radiation, Water, and Enforcement and Compliance Assistance have developed priority science questions. This document did not utilize an exhaustive search of all related historical research to address these questions. Instead, it focused on synthesizing the more recent (primarily within the last 10 - 15 years) research and scientific/technical tools. Where answers are not available, this document has at a minimum conveyed the state of science surrounding these questions. The priority science questions are listed below and are addressed in the following sections.

Section 2: Air Emission Characterization and Management

1. What are the air pollutants (e.g., dusts, volatile organic compounds and ammonia), their sources (including housing, storage ponds, lagoons, litter piles, and land application fields), and their emission rates from AFOs, and what metrics, methods, and models should we use in the future to quantify and monitor these emissions to better understand their relationship to atmospheric deposition and the formation of ground-level ozone and $PM_{2.5}$?

2. What are the meteorological (e.g., arid vs. wet conditions) and other variables (e.g., feed management, size of operation, type of operation (finishing), and application rates) that affect the emissions, and volatilization, transport, and deposition of AFO-related pollutants?

3. What are the most effective practices (e.g., covering lagoons, animal housing) and technologies (e.g., employing methane digesters) for reducing emissions of ammonia, criteria pollutants, and dust?

Section 3: Nitrogen Source Tracking

4. What methodologies can be used to distinguish the source(s) of nitrogen in ground or surface waters (e.g., specific animal species, septic tanks, fertilizers)?

Section 4: Pharmaceuticals and Pathogens

5. What specific analytic methods should be used in an environmental setting for the veterinary pharmaceuticals and microorganisms most likely to be found in the environment and most likely to be linked to adverse human health effects, e.g., drugs such as tetracyclines, sulfonamides, and trenbolone and microbes such as *Cryptosporidium parvum, Campylobacter spp., and E. coli* O157:H7?

6. How can we determine the fate, transport, and environmental impacts of pharmaceuticals and pathogens?

7. What is the strength of the evidence that demonstrates linkages between exposures to AFO contaminants and incidents of disease, especially infectious diseases caused by pathogenic organisms originating from AFO wastes (other than acute problems where it is obvious that agricultural runoff has entered drinking water supplies)?

Section 5: Manure Management

8. What are the most effective strategies and practices for minimizing the movement of pollutants from animal confinement areas, manure storage areas, and land applications of manure into surface and ground waters and limiting emissions into the atmosphere?

   Include:

   a. How reducing entry into one media may affect loadings into other media;

   b. For land application of manure, how pollutant movement is affected by (1) the form and amount of manure that is applied, (2) the timing, location, and method of application, and (3) the presence or absence of tile drainage systems in land application fields; and

   c. Consideration of the costs and ease of implementation of the identified technologies and practices.

9. What are the best alternative uses of manure, other than land application? Consider the:

   a. Health and environmental impacts; and

   b. Costs and ease of implementation of the identified uses.

Section 6: Environmental Risk Management Methodologies and Approaches

10. What tools (e.g., models, software) are available to farmers, watershed authorities, consultants and other stakeholders that can help them identify specific conditions (e.g., weather, soil type, hydrogeological characteristics) and geographical locations where animal feeding operations would present a higher risk to water quality?

11. What environmental assessment methodologies/approaches are available to evaluate farming operations and practices in order to determine their contributions toward causing or effectiveness in preventing adverse environmental impacts?

1.4 Executive Summary

1.4.1 Air Emission Characterization and Management

Background

Emissions from animal feeding operations (AFOs) can be released directly from the animals and can be products of manure decomposition. Animal feeding operations emit particulate matter (PM), ammonia, nitrous oxide, hydrogen sulfide, methane, volatile organic compounds (VOCs), hazardous air pollutants (HAPs), and carbon dioxide. There are three sources of emissions: animal confinement facilities, manure management systems, and manure land application sites. The methods that historically have been used to estimate emissions from AFOs are direct measurement and the application of emission factors. Regression analysis and process-based mass balance approaches are estimation methods that may be developed in the future. Each of these approaches, however, relies on comprehensive emissions data that currently are lacking for AFO processes.

Question: What are the air pollutants (e.g., dusts, volatile organic compounds, and ammonia), their sources (including housing, storage ponds, lagoons, litter piles, and land application fields), and their emission rates from AFOs; and what metrics, methods, and models should we use in the future to quantify and monitor these emissions to better understand their relationship to atmospheric deposition and the formation of ground-level ozone and $PM_{2.5}$?

Emission Rates for Pollutants From AFO Operations

Emissions can vary substantially among AFOs. The substances emitted and the mass quantity of emissions depend on manure characteristics and whether the microbial breakdown of manure occurs under aerobic or anaerobic conditions. Even for a specific animal type and type of manure management system, emissions can vary from farm to farm, depending on climate and operational factors. The primary factors that influence emissions are pH, high temperature, precursors, manure residence time, and whether manure is handled in a wet or dry form.

Differences in operating practices can affect emissions substantially. For example, dry manure management systems that are well operated will not be significant sources of hydrogen sulfide, VOCs, and methane because the manure decomposes aerobically. A dry system that is poorly operated, however, due to improper design or management (e.g., excessively high animal density, inadequate ventilation, poor drainage, watering system leaks) can prevent the manure from drying and allow anaerobic microbial activity. During anaerobic decomposition, hydrogen sulfide, VOCs, and methane are emitted. As another example, manure residence time can be an important variable affecting emissions of gaseous compounds. Therefore, the frequency of manure removal (e.g., daily versus several times a day) and the length of time that manure is retained in various system components prior to land application can affect emissions.

Emissions from AFOs also can vary significantly over the year. The magnitude of variation depends primarily on the degree of seasonal variation in temperature. The seasonal variation in emissions due to ambient temperature changes is greatest in cold climates. On an annual basis, however, there may be little difference in emissions from similar AFOs in cold and warm climates. Other factors that lead to emission variability are seasonal variations in the numbers of animals confined and feeding practices. Feeding practices that affect manure characteristics (i.e., composition of volatile solids, nitrogen, and sulfur) will vary depending on animal age, stage of production (e.g., lactating versus dry dairy cows), animal performance (e.g., rate of weight gain or milk or egg production), genetics, and feeding strategies.

These and other sources of variability lead to variations in emissions seasonally, geographically, and among similar AFOs. This variability suggests that an emissions estimate based on short-term monitoring may be a poor predictor of average or typical emissions. Emissions studies must be conducted over a sufficient time period to capture seasonal differences and differences in operational practices throughout animal production cycles.

Tools for Quantifying and Monitoring Emissions

No standardized methods for measuring or estimating emissions from AFOs have been developed, although emissions of gaseous substances and PM from AFOs have been measured extensively using a variety of techniques. No consensus exists as to the best methods for sampling AFO sources, and the analytical methods developed by EPA have not been validated on the matrix of gases emitted by AFOs. Another limitation is the absence of standard measurement units that link an emissions rate to the activity that was responsible for the emissions.

Few EPA test methods are applicable to AFO emissions sources, and a consensus on standards has not been developed by other organizations. Direct measurement of emissions typically involves measuring the concentrations and flow rate from a source of interest. This approach to quantifying emissions is well suited to conventional industrial emission sources in which vent characteristics are relatively constant. Measuring AFO emissions is difficult, however, because of the open nature of the emissions sources and the temporal and spatial variations in emissions. Moreover, emissions from open sources at AFOs are released over large surface areas at varying rates and are affected by local atmospheric conditions (e.g., wind speed and direction, background concentrations). At this time, direct measurement of most emissions sources at AFOs is impractical for purposes other than conducting research.

As part of a preliminary investigation into emissions from AFOs, EPA/OAQPS developed draft emissions factors for AFOs based on information gathered from literature. Although comprehensive emissions data are lacking, the draft emissions factors provide some insight into AFO emissions. The factors can be used to provide order-of-magnitude estimates for developing regional emissions inventories, to estimate relative amounts of emitted substances, and to compare relative emissions from different types of AFOs. The factors are not appropriate for estimating emissions from individual farms or for making regulatory determinations for any particular facility.

Regression analysis could produce more accurate emissions estimates than emissions factors. The approach requires a comprehensive data set that includes all of the parameters that are suspected of affecting emissions (e.g., animal type, animal age, AFO configuration, climatic conditions).

The EPA contracted with the National Academy of Sciences (NAS) to assess the scientific issues involved in estimating emissions from AFOs. In essence, the NAS concluded that there are too many variables for an emissions factor approach to work for individual farms. As an alternative, the NAS recommended pursuing a process-based approach to estimating emissions at the farm and regional level. Such an approach would begin by considering feed intake and use mass balance principles to account for the inflows, outflows, and sinks of substances as manure passes through the farm system. The approach would use mathematical modeling and experimental data to simulate conversion and transfer of reactants and products at each step and, therefore, would account for the interactions between various AFO components.

The process-based approach would be used for gaseous emissions that are generated from manure precursors (e.g., ammonia, nitrous oxide, hydrogen sulfide). The approach could not be applied to PM because these emissions are from entrainment of dried materials rather than from manure breakdown. At this time, available data are not sufficient to develop process-based models with a high degree of accuracy. Also, the composition of feeds and manure can vary substantially from farm to farm based on individual animal management practices. Data on average or typical values may not be representative of any given farm.

Research Needs

Research needs include developing a methodology to credibly integrate variability factors into an emissions estimation model. Developing methods to compare reported values among studies and to delineate the effect of variables (e.g., manure loading rate, surface area-to-volume ratio) to develop valid functional relationships is another important area for further research. Additional studies of regression analysis also need to be conducted because available studies generally have not focused on total emissions from all AFO components. Another area in which data are lacking is the conversion mechanisms that govern formation of gaseous substances from manure precursors. In addition, substantial new data collection and research will be needed to develop process-based models.

Question: What are the meteorological and other variables that affect the emissions, transport, and deposition of AFO-related pollutants?

The lifetime of AFO emissions in the atmosphere can vary from less than a day to many days, depending on the substance emitted, atmospheric stability, solar radiation, precipitation, and presence of reactive compounds in the air. Ammonia, hydrogen sulfide, and VOCs can participate in atmospheric chemical reactions that influence ozone and fine particle formation and acid deposition. Therefore, AFO emissions are converted to other compounds and deposited back to the earth in one of several forms.

Ammonia in the atmosphere can be present as both free (gaseous) ammonia and ammonium ($NH4_4^+$), which is formed when ammonia is dissolved in water. When bicarbonate (CO_3^{2-}), chloride (Cl^-), nitrate (NO_3^-), sulfite (SO_3^{2-}), or sulfate (SO_4^{2-}) ions also are present in the air, ammonium salts (e.g., ammonium nitrate and ammonium sulfate) are formed. These salts exist as fine particulate aerosols.

The residence time of atmospheric ammonia can vary from hours to days. Because ammonia and ammonium salts are water soluble, removal can occur by wet deposition during periods of precipitation. Otherwise, dry deposition due to gravity is the primary removal mechanism for ammonium salts and gaseous ammonia adsorbed on particulates. Gaseous ammonia also can be adsorbed directly on plant and soil surfaces. Because gaseous ammonia has a relatively short residence time in the atmosphere, it is deposited near the emission source. Depending on meteorological conditions, ammonium aerosols can be deposited close to the emission source or can be transported greater distances from the source before removal by either wet or dry deposition.

Both wet and dry ammonia deposition can cause ecological damage. Ammonia deposition can directly impair surface water quality by creating eutrophic conditions that lead to fish kills and an overall decline in marine organisms. Ammonia deposition also can contribute to the acidification and consequent disruption of acid-sensitive terrestrial and fresh water aquatic ecosystems. Acidification occurs primarily when ammonium sulfate and ammonium sulfide are transformed to sulfuric acid by nitrification reactions that occur in soils and surface waters.

The residence time of hydrogen sulfide in the atmosphere can range from hours to days, depending on atmospheric conditions. In the atmosphere, hydrogen sulfide can be oxidized to sulfur dioxide and then sulfur trioxide, which reacts with water to form sulfuric acid. Oxidation to sulfur trioxide (sulfite) proceeds rapidly if metallic catalysts, such as iron and manganese oxides, common products of combustion processes, are present. If ammonia or another cation is present, a reaction to form a fine particulate aerosol will occur. If not, sulfuric acid will be formed. Because hydrogen sulfide is water soluble, removal also can occur by wet deposition. Once deposition occurs, hydrogen sulfide will be oxidized microbially to sulfuric acid. Therefore, hydrogen sulfide emissions can be responsible for the acidification of surface waters and soils both by direct deposition or following oxidation in the atmosphere to sulfate.

The atmospheric residence time of VOCs ranges from hours to months, depending on the species. VOCs, in the presence of sunlight and nitrogen oxides, contribute to the formation of ground-level ozone, which can be transported over long distances. In addition to ozone formation, VOC species can be oxidized ultimately to carbon dioxide and water by hydroxyl radicals, oxygen, and ozone. VOCs can be removed from the atmosphere by adhering to land and plant surfaces, and soluble VOCs are removed through wet deposition.

Typically, the atmospheric residence time of PM ranges from 1 to 10 days. The length of time that particulates remain airborne varies by particle size. Larger particles settle by gravity in the vicinity of the emission source, and fine particulates are transported farther downwind (similar to gaseous compounds). Particulates are removed by both wet and dry deposition.

Question: What are the most effective practices (e.g., covering lagoons, animal housing) and technologies (e.g., employing methane digesters) for reducing emissions of ammonia, criteria pollutants, and dust?

Strategies for Reducing Emissions

There are three strategies for reducing emissions from AFO processes: (1) inhibiting the formation of substances; (2) suppressing emissions of substances once formed; and (3) capturing and controlling substances emitted. Emission control strategies for AFOs can involve different combinations of inhibition, suppression, and control techniques. The availability of control strategies is highly site specific, depending on the objectives of control, the types of manure management systems currently in place, and climate. In some instances, different control strategies might be required for different pollutants.

Inhibition techniques essentially are pollution-prevention methods that either reduce the amount of nitrogen and sulfur in manure (e.g., diet modification) or remove the conditions that favor formation of ammonia and hydrogen sulfide once excreted. Although inhibition techniques are not expected to result in emission reductions that are comparable to add-on control technologies, inhibition techniques reduce unnecessary emissions.

Suppression techniques prevent the release of PM or gases (ammonia and hydrogen sulfide and VOCs that are highly soluble in water) once they have been generated (e.g., covering of manure storage tanks). Because suppression does not physically alter or destroy substances, they can be emitted when manure is transferred to a downstream location that is not controlled.

Control techniques can reduce emissions of PM and gases either by capturing emissions or by physically altering the chemical composition of the compounds (e.g., biological covers on anaerobic lagoons will convert hydrogen sulfide to sulfur dioxide).

Research Needs

Relatively little research has been conducted to quantify the costs and long-term effectiveness of the technologies that have been identified to date. Many control-technology studies have focused on mitigating odors at particular locations or reducing emissions from a single source (e.g., a confinement house for purposes of protecting animal or worker health).

These studies often do not address the fact that emissions reduced at one AFO component (e.g., confinement) may be emitted later at another component (e.g., manure storage), or that methods to control one pollutant may increase emissions of others. Control technology effectiveness, therefore, must be evaluated based on the design characteristics of each AFO and the effect on total emissions from the entire operation (i.e., confinement, manure management systems, and land application) for each substance of concern. In addition, although many technologies have been evaluated on a farm-scale basis or are being utilized to some degree in animal agriculture or similar industrial processes, many techniques have been demonstrated only in a limited variety of commercial operating conditions.

1.4.2 Nitrogen Source Tracking

Background

Nitrogen found in surface and ground waters often comes from undetermined or nonpoint sources. It is difficult to trace an inorganic compound such as nitrogen to its original source. The development and implementation of technology and the understanding of geochemical processes that influence the flow of nitrogen through ecosystems has made this task easier. Tracing nitrogen compounds is not an exact science, and no single methodology can differentiate between the many sources of nitrogen in the environment.

Question: What methodologies can be used to distinguish the source(s) of nitrogen in ground or surface waters (e.g., specific animal species, septic tanks, and fertilizers)?

Methodologies for Nitrogen Source Tracking

A number of studies have reported success using stable isotope tracking, which has been in use since the mid-1970s. Although there are limitations because of the many variables in nitrogen forms, isotope tracking is one of the only ways to track an inorganic substance such as nitrogen.

Nitrogen found in the atmosphere is composed of 99.637 percent ^{14}N, with the remaining 0.363 percent represented as ^{15}N. This ratio of ^{15}N to ^{14}N is referred to as the atmospheric standard. Most ecological studies express nitrogen isotopic compositions in terms of $\delta^{15}N$, which are parts per thousand differences from the atmospheric standard. Many studies have shown the correlation between high concentrations $\delta^{15}N$ and animal waste in surface and ground waters. It still is difficult, however, to differentiate animal and human sources via nitrogen isotopes. The many variances in soil type, climate, weather patterns, and land use make it difficult for a single method to determine a single source of nitrate contamination. The idea of combining several isotope tracking methods might be a workable solution to these limitations.

Isotopes of oxygen (^{18}O) have been used in combination with ^{15}N to trace contaminated ground water. ^{18}O has proven a useful tracer in differentiating a contaminant plume originating from a single septic system. ^{18}O is more effective at showing processes involved in nitrogen cycling rather than source tracing, however. ^{18}O from NO_3 has been used together with ^{15}N to determine the extent of denitrification (the rate of NO_3 removal from the nitrogen pool) occurring in soils.

Studies also have combined geochemical data with isotopic tracers to distinguish agricultural and residential land uses. Because multiple land uses might provide fertilizers as a nitrogen source and because manure application can create elevated $\delta^{15}N_{NO3}$ values similar to septic waste, additional geochemical criteria might need to be employed to delineate the source of contamination. Many modern statistical computer packages contain classification-tree models that might be useful in determining nitrate sources utilizing $d^{15}N$ with other geochemical parameters. The methods and parameters would likely need to be modified for different geographic regions or for specific source contaminants.

Other methods are proving helpful in distinguishing human and animal source contamination via bacterial source tracking. Further research might provide interesting results from the combination of bacterial source tracking and isotope tracking.

<u>Research Needs</u>

The science of using stable isotopes is becoming a valued technology that continues to evolve. Ratios of stable nitrogen isotopes cannot differentiate between every possible source of nitrogen but, by combining this knowledge with other geochemical and statistical principles, more confidence in the validity of source identification will occur.

Ongoing research is providing more insight into the study of nitrogen isotopes and into natural transformations of nitrogen in the environment. Pinpointing the source of a nitrogen atom might not be possible, but more research in the areas of nitrogenous compounds and transformations is needed to further develop the potential of nitrogen source tracking. In addition, hydrogeological principles are needed to further understand the flow of ground water, surface water, and runoff when determining how nitrates enter water systems.

1.4.3 Pharmaceuticals and Pathogens

<u>Background</u>

___ Pharmaceuticals and pathogens from animal feeding operations (AFOs) may present a significant risk to human health. Pathogens may cause serious illness and even death in humans, the use of antibiotics creates antibiotic-resistant organisms that may inhibit the effectiveness of human medications, and endocrine-disrupting chemicals (EDCs) may interfere with human reproductive function. These materials generally enter the environment in livestock manure and urine via runoff from land application or confinement areas. Based on the concentration of livestock and the management of manure at a facility, the amount of pathogens, antibiotics, and EDCs in surrounding areas have the potential to impact human health negatively.

Question: What specific analytic methods should be used in an environmental setting for the veterinary pharmaceuticals and microorganisms most likely to be found in the environment and most likely to be linked to adverse human health effects (e.g., drugs such as tetracyclines, sulfonamides, and trenbolone; and microbes such as *Cryptosporidium parvum, Campylobacter spp.,* and *E. coli* O157:H7)?

Analytic Methods Available for Use in an Environmental Setting

Based on the uncertainty of health affects from pathogens, antibiotics, and EDCs, analytic methods can be used to understand their impacts on humans and the environment. Laboratory analytic methods are used by industries and municipalities to analyze the chemical and biological components of wastewater, drinking water, sediment, and other environmental samples that are required by regulations under the authority of the Clean Water Act and the Safe Drinking Water Act. This testing supplies information about the amount of pathogens, antibiotics, and EDCs making their way into the environment and potentially into the drinking water.

Specific analytic methods have been developed for detecting pathogens, including protozoa (*Cryptosporidium* and *Giardia*), bacteria (*E. coli*, enterococci, and *Campylobacter*, *Arcobacter*, and *Helicobacter*), and viruses, in water, fecal samples, soils, and air. Analytic methods for antibiotics currently are effective in foods but are problematic for soils. More sensitive methods for analyzing water for antibiotic compounds away from the source also need to be developed. Because EDCs represent a broad spectrum of compounds, the development of analytic techniques is challenging. Biological screening tools and direct measurement techniques have been developed to detect EDCs, and additional techniques are under development.

Research Needs

Additional research is needed to standardize analytic methods for pathogens, antibiotics, and EDCs. Standardization will allow quality assurance and quality control procedures to be useful. In addition, a database of current research and resources provides basic information for all researchers. Research on pathogens, antibiotics, and EDCs is evolving and changing constantly. In instances that involve a wide variety of chemicals or microorganisms, an integrated approach to analytic methods should be used for environmental detection. As analytic technologies advance, the ability to locate, detect, and understand pathogens, antibiotics, and EDCs will allow for better regulation of these substances in the environment.

Question: How can we determine the fate, transport, and environmental impacts of pharmaceuticals and pathogens?

Air, soil, and water are affected directly and indirectly by pathogens and veterinary pharmaceuticals from AFOs. Potential risks to humans and to aquatic and terrestrial species include ecotoxicological effects (i.e., acute and chronic toxicity, genotoxicity, and carcinogenicity), pharmacological effects (from effects on nontarget organisms, such as interference with hormonal and immune systems), and resistance development of microorganisms.

Pathogens

______*Fate, Transport, and Environmental Impacts.* Pathogens are shed and present in animal feces. Manure management practices affect the survival times of pathogens. Temperature is probably the most important factor in determining pathogen survival times in manure. Other factors affecting survival times include ammonia, high pH, desiccation, and competition.

Few models have been developed to determine the fate, transport, and environmental impacts of pathogens. Existing models include probabilistic models to quantify nonpoint sources of pathogen production and to predict virus attenuation, empirical overland flow models, a microbial flow submodel for the Soil & Water Assessment Tool, and a Hydrologic Simulation Program Fortran Model.

Current Methods and Research. Research is being conducted on the genetics of antibiotic resistance and manure management practices and their effects on pathogen transport through soil and water.

Research Needs. Research is needed to increase the knowledge base regarding sources of pathogens, effects of natural processes on pathogens, development of pathogen environmental fate and transport models, transport properties, and manure management practices to reduce the transport of pathogens.

Pharmaceuticals

Fate, Transport, and Environmental Impacts. Environmental exposure to veterinary pharmaceuticals such as antibiotics and EDCs occurs via emission and distribution routes that are similar to those of pathogens. Veterinary pharmaceuticals are ingested, injected, and applied topically. The major uses of veterinary pharmaceuticals are as growth promoters, antibacterial agents, and antiparasitic agents.

Routes by which veterinary pharmaceuticals enter the environment include removal and subsequent disposal of waste materials, excretion of feces and urine by grazing animals, spillage during external applications, direct exposure/discharge into the environment, soil contamination, leaching to shallow groundwater from manured fields, surface runoff to water and soil, airborne contamination through topical applications, and biota uptake.

Current Methods and Research. Available models for fate, transport, and environmental impacts of veterinary pharmaceuticals are limited. Appropriate data and test methods that are specific for these substances are lacking. Current pharmaceutical fate studies have been performed only on human pharmaceuticals that are used as veterinary drugs. These studies also have been survey oriented and have documented only occurrence in a variety of environmental systems.

Research Needs. Additional research is needed in areas such as usage data, emission routes, ecotoxicity, endocrine-disrupting potential of hormones and other substances, and collection of temporal and spatial distribution data and environmental degradation rates for pharmaceuticals in the United States.

Question: What is the strength of the evidence that demonstrates linkages between exposures to AFO contaminants and incidence of disease, especially infectious diseases caused by pathogenic organisms originating from AFO wastes (other than acute problems where it is obvious that agricultural runoff has entered drinking water supplies)?

Strength of Evidence Linking Outbreaks to AFO Contaminants

Because fecal pollution can come from several sources, tracing the pathogens to their exact source is challenging. Based on the need to distinguish between sources of fecal pollution, new methodologies have emerged. These can be categorized into several groups, including microbiological, genotypic, phenotypic, and chemical methodologies. The methodologies can be used individually or in combination.

Fecal source tracking research often begins with epidemiological data. Researchers conduct interviews with infected patients to discover the common source of an outbreak, which might be foodborne, waterborne, via human-to-human contact, recreational, or from direct contact with livestock. Such research allows scientists to narrow their search for the source of an outbreak. This type of study does not scientifically prove a contamination source; however, it provides critical information for beginning laboratory research. Another method used by researchers is the Livestock Density Indicator. Spatial analytic techniques provide another means of identifying populations at risk for pathogen infections. These studies, however, do not locate the exact source of contamination that causes an outbreak.

Recent research provides information on the ability to use fecal source tracking to link human outbreaks of disease and AFO contaminants. There are three general types of studies. Waterborne outbreak studies use fecal source tracking to link an outbreak to a water supply. These studies have found that human diseases were linked to a common water source and that the water source most likely was contaminated by an animal. The studies, however, did not define the specific animal source (e.g., production animal or wildlife). In most cases, speculation is made based on epidemiological data. Foodborne outbreak studies have linked an outbreak to a food source but have not explained how the food source became contaminated. Some such studies cite epidemiological data to provide a clue to the source. Another study directly linked AFO contaminants to human incidence of disease via serotyping, phage typing, biotyping, and pulsed field gel electrophoresis.

Research Needs

Because only one study has emerged that can conclusively link an outbreak to AFO contaminants, research needs to continue on the various methodologies to determine the best method or methods for tracing fecal contamination. It is likely that no single method will be able to make the connection. Instead, several methods likely will emerge as the best choice for tracing an outbreak back to its source. Combining several methods will strengthen the results. Nonmolecular methods (phenotypic and chemical) are advantageous early in fecal source tracking to discriminate quickly between human and animal sources. Nonmolecular methods also usually are inexpensive and can be performed on hundreds of isolates per week. Molecular methods (genotypic) can be used later in the process to validate results. These methods can reveal unique DNA differences in fecal bacteria and can match the DNA of an outbreak organism to that of an organism in the manure of a production animal.

Further research will help answer questions about the strengths of methodologies and streamlining the process for source tracking. A suggestion for future research is to create a national library of *E. coli* isolates for humans and animals to help track and identify fecal pollution. Another suggestion is to compare fecal source tracking methodologies with standard methods. Additional studies comparing methodologies will help address problems related to detection limits, the temporal and spatial variability of markers, and reproducibility of assays.

Because of the diversity of animal types and intrinsic evolutionary processes in microbial organisms, these methods never will be completely accurate. The challenge for any research is to recognize the patterns that cannot be classified and determine when an increased effort to refine methods and build libraries produces diminishing returns. Perhaps a "toolbox" approach to studying the source of contamination might work best to expedite the process and verify results. As more studies are conducted, the advantages and disadvantages of each fecal source tracking method will become clear. This will allow development of the best possible resources for determining the source of human outbreaks from AFO contamination.

1.4.5 Manure Management

Background

Waste management at confined animal feeding operations (AFOs) includes a series of fundamental activities: waste production, waste collection, waste transfer, waste storage, waste treatment, and waste utilization. The specifics of these activities differ by the type of livestock produced. Regardless of the specific pathways of waste management in a particular AFO, pollution control strategies and practices can be applied to each of the stages in waste management.

Question: What are the most effective strategies and practices for minimizing the movement of pollutants from animal confinement areas, manure storage areas, and land applications of manure into surface and ground waters and limiting emissions into the atmosphere? Include:

a. How reducing entry into one media may affect loadings into other media;

b. For land application of manure, how pollutant movement is affected by: (1) the form and amount of manure that is applied; (2) the timing, location, and method of application; and (3) the presence or absence of tile drainage systems in land application fields; and

c. Consideration of the costs and ease of implementation of the identified technologies and practices.

Strategies and Practices for Minimizing Movement of Pollutants

Feeding strategies reduce the concentration of pollutants in the waste stream and include formulating diet more precisely, enhancing the digestibility of feed ingredients, genetically enhancing cereal grains and other ingredients to promote increased feed digestibility, and improving quality control. These strategies increase the efficiency with which animals use the nutrients in their feed and decrease the amount of nutrients excreted in waste.

Some treatment systems store waste as well as change its chemical, physical, or biological characteristics. Engineered systems such as anaerobic lagoons are the most common form of treatment for AFOs. Other technologies, such as aerated lagoons for liquids and composting for solids, use oxidation to break down organic matter. Additional treatment options include chemical amendments to change nutrient forms or reduce pathogens and vegetative treatment of concentrated waste sources.

The goals of land application should include utilizing manure nutrients optimally, reducing the movement of manure and constituents offsite, and preventing the delivery of polluted runoff to surface or ground waters. Decisions on the amount, form, timing, and method of waste application represent the implementation of a nutrient management plan. Application rates should be tailored to provide adequate nutrient supply for crop needs without leaving large amounts that are vulnerable to runoff or leaching after harvest. This determination is based on soil testing, manure analysis, yield goals, and crop nutrient needs. Application timing is extremely important because the longer manure remains in the soil before crops take up the nutrients, the more likely those nutrients are to be lost through volatilization, denitrification, leaching, erosion, and surface runoff.

Surface versus subsurface application is a key issue. Simply applying manure to the soil surface can lead to losses of most of the available N, depending on soil temperature and moisture. Reductions in atmospheric losses of N by incorporation result in greater N remaining in the soil and, thus, a greater potential for leaching losses, especially later in the growing season. For this reason, changes in atmospheric losses as a result of application methods must be accounted for in decisions about overall nutrient application rates.

Manure injection has been reported to reduce surface losses of indicator organisms, and subsurface applications may reduce manure contact with surface soils and tend to increase bacteria transport to tile drains or ground water. It is now recognized, however, that preferential flow paths through macropores in the upper soil horizons easily can transmit microorganisms and particulate matter to tile drains. This may increase bacteria transport to tile drains or groundwater.

The presence of artificial subsurface drainage on agricultural fields can be a major influence on pollutant transport and delivery. There is ample evidence that tile drainage significantly affects water quality. Tile drainage can be a major pathway for delivery of N and P to surface waters. Management practices that can be used to reduce pollution through tile drainage include: (1) not applying wastes when tile drains are already flowing or within 72 hours of a runoff event; (2) plugging drainage lines and allowing them to be filled with water prior to land application of waste; and/or (3) avoiding spreading waste directly over drainage lines.

The costs and benefits of practices and strategies to protect the environment vary across animal types, facility sizes, waste management handling systems, and local site conditions (including climate and availability of land on which manure can be spread). The applicability of these practices and strategies also is largely site specific, particularly when considering the type and degree of management required to implement them.

Costs and benefits can be estimated and represented in several ways, with unit costs and case-study or model-farm costs being two of the more common approaches. Unit costs are useful in developing cost estimates for specific facilities but can be misleading in the absence of facility-level applications. Animal waste management systems typically integrate many specific practices and strategies, with each single practice affecting the cost and effectiveness of the other practices, making overall cost analysis challenging.

Research Needs

There are many gaps in the knowledge of the effectiveness of individual management practices. Some innovative practices that have not yet been applied or tested widely include animal treatment for pathogen control and waste treatment options such as gasification, pyrolysis, and various chemical treatments proposed to reduce the levels of pathogens. Other practices, such as feeding strategies, nutrient management, and riparian buffers, have a good theoretical basis but lack validated research on real-world applications. Similarly, much is still to be learned regarding the cost and effectiveness of manure digestion/treatment options, including anaerobic digesters for methane production and recovery, secondary biological treatment, and sequencing batch reactors. Such gaps in understanding should be addressed by carefully designed experiments conducted at the field or farm scale.

Past studies repeatedly have shown that the combined effect of a set of practices implemented across a farm or watershed rarely represents the sum of the effects of individual practices. Thus, there is a great need for comprehensive, holistic research on the effectiveness of overall good management on water, soil, and air quality at the farm, watershed, and regional scales. Research that follows each drop of water and each pollutant input to establish the mechanisms and quantify losses from waste production, treatment, and application is needed to truly understand how the effects of various practices accumulate on the farm and across watersheds. This type of research could entail establishing a set of model farms at which a complete set of practices is implemented.

Question: What are the best alternative uses of manure, other than land application?

Alternative Uses of Manure

In areas in which the amount of manure produced exceeds the land application capacity, some producers export manure. In such cases, manure is sold or transferred from the farm to be used on other agricultural operations where land is available. Some states, such as Delaware and Maryland, have established systems of manure trading or brokering to facilitate such transfers. Farmers also might use such systems to connect with individuals who are pursuing alternative uses for manure. These uses might include burning for cogeneration of power, fertilizer manufacturing, and composting. The management considerations regarding protecting water quality that apply to the original producers of manure apply to subsequent agricultural users of exported manure as well.

Because of its fertilizer value, manure often is used as a fertilizer or soil conditioner in nonagricultural situations in which manure nutrients can be recycled. Manure, sometimes mixed with other organic materials, is applied to forested lands, on construction sites, in developing land to control runoff and soil erosion, and as a peat substitute in greenhouses. The combination of coal combustion byproducts and dairy manure as a soil amendment has been investigated, but the leaching of metals made the mixture unsuitable as a soil amendment material.

Composting of animal waste alone can provide a salable consumer product. In addition, animal waste is an important ingredient in composting operations in which other materials are processed. With processing, animal wastes have been converted into commercial fertilizer products. Pelletizing can be done to change the N and P ratios to match typical plant growth requirements more closely. Pelleted nutrients have reduced moisture content, fewer odors, and reduced transportation costs. Central manure treatment facilities have been proposed in areas of concentrated animal production to extract high-value fertilizer suitable for wide distribution.

Research Needs

Alternative uses of animal wastes is an area in which additional research is needed. The potential for marketing compost products has been studied, but research into a much broader range of applications might be warranted.

1.4.5 Risk Management

Background

The concentration of animal populations within relatively small geographic areas over the past few decades has upset the balance between supply and demand for animal waste. A range of pollutants can be introduced to the environment from animal feeding operations (AFOs) through land application of animal wastes. The extent to which an individual farm contributes pollutants depends on a wide range of physical factors, including soils, landscape, climate, the type of animals, and farm management. Not all agricultural operations cause water quality problems, and not all parts of the landscape contribute equally to water quality problems. Concerns associated with both siting and management must be addressed to minimize the movement of pollutants from AFOs and the lands on which animal waste is applied. A variety of assessment techniques, screening tools, and models exist that can help producers and managers identify conditions and practices that represent a high risk to water quality and other adverse environmental impacts.

Question: What tools (e.g., models, software) are available to farmers, watershed authorities, consultants, and other stakeholders that can help them identify specific conditions (e.g., weather, soil type, hydrogeological characteristics) and geographical locations where animal feeding operations would present a higher risk to water quality?

Available Tools

Farm Management Planning Tools. Many screening tools and decision support systems are available that perform farm-scale analysis useful in animal waste management. Examples include Animal Waste Management (AWM); AFOProTM, a stand-alone nutrient management planning tool with optional connections to GIS and AWM; and Manure Management Planner (MMP).

Pollutant Loading and Water Quality Assessment Models. Over the past several decades, numerous mathematical models have been developed to understand, quantify, and simulate the movement of nonpoint-source pollutants from land to water. Although some of these models do not apply, others might be used as screening tools to assess risks to water quality from agricultural operations. By understanding the fate and transport of manure pollutants and the effectiveness of management practices, producers and managers can evaluate farming operations and take steps to prevent adverse environmental impacts. Examples of the models include the

Leaching Estimation And Chemistry Model (LEACHM); MANure Nitrogen Evaluation Routine (MANNER); Nitrate Leaching and Economic Analysis Package (NLEAP); Root Zone Water Quality Model (RZWQM); Erosion/Productivity Impact Calculator (EPIC); SimUlation of Nitrogen Dynamics In Arable Land (SUNDIAL); Groundwater Loading Effects of Agricultural Management Systems (GLEAMS); Dairy Forage System Model (DAFOSYM); PLOAD, a simplified, GIS-based model used to calculate pollutant loads for watersheds; Generalized Watershed Loading Function (GWLF); MIKE-BASIN, a GIS-based water resource modeling software for integrated river basin planning and management; Agricultural Nonpoint Source Pollution (AGNPS); Simulator for Water Resources in Rural Basins—Water Quality (SWRRBWQ); Soil and Water Assessment Tool (SWAT); Hydrological Simulation Program—Fortran (HSPF); and Better Assessment Science Integrating point and Nonpoint Sources (BASINS).

Feed Management and Water Quality Modeling. It is well known that feed management strategies have an effect on the amount of livestock manure produced. Feed management activities might be used to reduce the nutrient content of manure, resulting in less land being required to effectively utilize the manure. Feed management activities usually are dealt with as a planning consideration. AFO owners, however, are encouraged to incorporate feed management as part of their nutrient management strategy. Though the effectiveness of feed management in changing nutrient composition is well recognized, actual net effects on water quality are not well documented.

Risk Assessment Programs. Farm*A*Syst is an agricultural self-assessment resource that enables operators to determine the risk their operation might pose to water quality. It uses a series of fact sheets and questionnaires to help producers identify the effectiveness of their management practices, identify alternative measures, and prioritize areas that need improvement.

The America's Clean Water Foundation (ACWF) On Farm Assessment and Environmental Review (OFAER) is an assessment program for livestock producers that uses certified professionals to determine an operation's environmental risks. Assessment tools focus on overall site management, building and lot management, manure storage and handling, mortality management, and nutrient management.

Research Needs

There is a great need for the validation of models for use in risk assessment. Not all models developed to simulate nonpoint-source pollutants from land to water are appropriate for agricultural risk assessment. Because of complexity and requirements for data and expertise, sophisticated physical process simulation models often are difficult to apply in real-world situations. In addition, more studies are needed on coupling feed management with water quality models.

Question: What environmental assessment methodologies/approaches are available to evaluate farming operations and practices in order to determine their contributions toward causing or effectiveness in preventing adverse environmental impacts?

Methodologies for Evaluating Farming Practices

Farmers, consultants, and watershed authorities have access to a variety of tools for evaluating farming operations to determine their contributions toward causing or preventing adverse environmental impacts. Some of these tools are simple index tools (e.g., the Phosphorus Index and the Nitrogen Leaching Index), some represent distinct exercises (e.g., Farm*A*Syst, On Farm Assessment and Environmental Review), and some are incorporated within the context of normal farm management (e.g., Comprehensive Nutrient Management Plans). In addition, a wide variety of incentive programs exists at both the federal and state levels that can help producers manage the risks of environmental impacts from their operations. Many of these incentive programs include both technical assistance in identifying risks, problems, and solutions and cost-sharing assistance for implementing changes in management. The specific application and utility of these tools and incentives depends on local needs and objectives.

An Environmental Management System (EMS) is a comprehensive environmental management approach developed for business and industry by the International Organization for Standardization (ISO), known as ISO statute 14001. The EMS process has been adapted to agriculture in recent years. An EMS is a voluntary, proactive, flexible, and individualized way for an industry to meet environmental and economic constraints and document its environmental stewardship. Many agricultural operations already have management plans in place. An EMS can aid in organizing these efficiently to help gain farm sustainability and achieve environmental goals.

Research Needs

An important research need in this area is the validation of models and management systems to determine their effectiveness in evaluating farming operations with the goal of pollution prevention. In addition, there is a need for research on the proper application of models for effective assessment of problems that cause, or solutions that decrease, adverse environmental impacts.